Empowering Sustainability: Integrating ESG Principles for a Net-Zero Future Through Decentralised Process Plant Design

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ABSTRACT

In the transition towards a net-zero future, the integration of Environmental, Social, and Governance (ESG) principles into decentralised process plant design plays a pivotal role. This study explores the potential of hydrogen production from biogas using reforming and electrolyser technologies, with a focus on remote areas. Leveraging ASPEN Plus® simulation software for reforming and Homer Pro for electrolyser-based production in Whyalla, South Australia, the study evaluates hydrogen production efficiency and environmental impact. Tri-reforming emerges as a standout method, offering notable improvements in key metrics. Compared to conventional methods, tri-reforming yields an 18.7% increase in hydrogen production, a 28.6% reduction in total energy consumption, and a 15.4% decrease in waste heat generation. Moreover, hydrogen production from biogas results in a 22% reduction in carbon dioxide emissions per ton of hydrogen produced, emphasizing its potential for sustainable energy solutions. The ESG calculation for the weighted average has been conducted, guiding the selection of plant design and technology setup in alignment with a new plant design framework. Consequently, reforming biogas has been chosen as the optimal method, showcasing its viability for addressing sustainability challenges.

Keywords

Sustainability; ESG Principles; Decentralised Process Plant Design; Hydrogen Production; Biogas Reforming

1. Introduction

The transition to a clean-energy economy faces critical challenges, with 2023 marking the hottest year on record and global temperatures surpassing the 1.5°C threshold[1]. Despite commitments from nearly 200 countries to increase renewable energy reliance and energy efficiency, progress remains slow, and greenhouse gas emissions persist at record levels [2, 3]. Achieving net-zero emissions requires substantial investments, estimated at $4.5 trillion over the next decade, with companies adopting science-based climate targets to align with net-zero by 2050 [4, 5]. Decentralizing the electricity grid and transitioning to a circular economy are essential strategies for curbing CO_2 emissions, with solar energy projected to meet 20% of the EU's electricity demand by 2040. In the chemical engineering landscape, a focus on circular economy principles and emissions reductions is paramount, guided by the GHG Protocol's categorization of emissions into three scopes. Increasing emissions disclosures globally may drive further climate action with regulatory measures [6]. Carbon credits for afforestation and methane control offer economical paths to emissions reduction, helping companies offset residual emissions and meet interim targets on the path to net-zero aspirations [7, 8]. These credits are increasingly recognized as a mechanism for unlocking private investment needed to fund the green transition in developing countries and supporting broader biodiversity goals. Robust ESG practices have been shown to reduce capital costs and enhance operational performance in 90% and 88% of cases, respectively, with a positive correlation to stock prices [4].

In advancing chemical engineering process design, focusing on GHG reduction, climate change mitigation, and ESG principles is crucial. Embracing Circular Economy models and employing a multi-criteria decision-making matrix aid in tailoring technologies, particularly in remote areas [9]. Low-carbon hydrogen, especially from biomass[2], is pivotal for achieving net-zero emissions by 2050 [10, 11]. This study highlights decentralised supply chains for hydrogen production from biomass as a compelling, often overlooked opportunity. They offer a means to generate low-carbon hydrogen while facilitating vital carbon dioxide removal, advancing towards a sustainable future.

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2. MATERIALS AND METHODS

The research introduces a groundbreaking method for decentralised hydrogen production using bio-gas feed streams, with broad applications across sectors. Validated with Aspen Plus and Homer Pro software, the extended chemical process plant design model integrates ESG considerations, surpassing conventional limitations. Location selection leverages NASA data in Homer Pro, ensuring alignment with sustainability metrics. The methodology optimises selection and risk management through a generalised ESG standard and weighted averaging, while also indicating carbon reduction and maturity for carbon budgeting. Figure 1 provides a succinct depiction of the process model, illustrating its implementation.

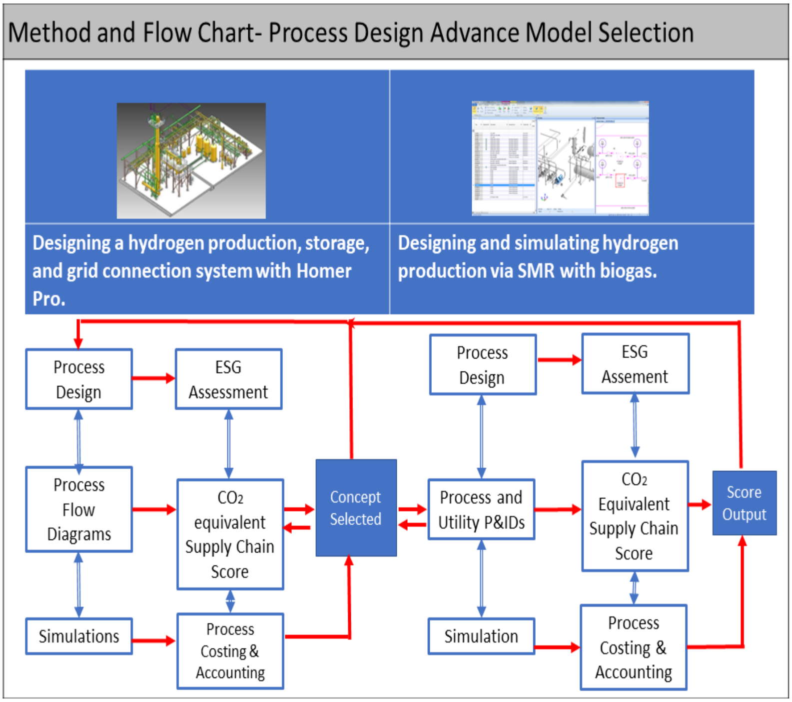

Figure 1: Methodology for current research work and process plant design and technological selection in ESG realm

2.1 Hydrogen Production using Bio-gas – Process Design and Simulation

In the engineering discussion, the optimisation of hydrogen production from biogas is paramount, focusing on minimizing heat loss, maximizing energy efficiency, reducing waste, and curbing carbon emissions. Utilizing Aspen Plus software and economic analysis tools, precise parameter assessment and adjustment are achieved. Advanced modeling techniques aim to achieve a minimum 95% conversion rate of feedstock to desired products. Key strategies include reactor design optimization for temperatures exceeding 800°C, waste heat recovery through heat integration, and carbon emission reduction via catalytic converters. Biogas as a feedstock aligns with sustainability goals, reducing reliance on fossil fuels. The study's rigorous simulation and economic analysis aim to identify the most cost-effective and environmentally sustainable approach to hydrogen production in line with the work of [12] as baseline for comparison and simulation[13]. Regarding utility costs, Total Utilities expenditure is $0.01358 million annually, surpassing the target by $0.001455 million, representing 110.71% of the actual cost with available savings of $0.02 million. Heating Utilities meet the target at $0.02233 million annually. Cooling Utilities deviate negatively, with actual costs at $0.008744 million, resulting in available savings of $0.007289 million, or 83.36% of the actual cost. Carbon Emissions expenses total $5.25 million annually, slightly above the $4.80 million target. However, available savings amount to $0.45 million, representing 90% of the actual cost.

2.2 Homer Pro- Electrolyser System for Hydrogen Generation & Storage

The electrolyser-based hydrogen production scenario presented utilizes Homer Pro software to configure an alkaline electrolyser tailored for an industrial sector in Whyalla, South Australia, Australia. The system integrates a renewable energy photovoltaic (PV) system with a converter for peak load management and AC to DC transmission. An autosized genset adjusts to the load manipulation requirements for hydrogen generation. The system simulation report offers a comprehensive overview, detailing the architecture, dispatch strategy, and performance metrics. The system comprises an Autosize Genset with a capacity of 5,100 kW, a system converter with a capacity of 72.0 kW, a Generic Electrolyser with a capacity of 100 kW, and a hydrogen tank with a storage capacity of 100 kg and an autonomy of 3.33 hours. The cost summary delineates the net present costs and annualized costs associated with each component, providing insights into capital, operating, replacement, salvage, and resource costs. The electrical summary in table 1 highlights excess electricity production and unmet electric load, elucidating system capacity and performance. For instance, the Autosize Genset annually produces 12,810,032 kWh of electricity, with a mean electrical output of 1,462 kW and fuel consumption of 3,678,198 L, which is mainly an add on for carbon emission, although being decentralised. The economics section juxtaposes the proposed system with a base system across various parameters such as net present cost, CAPEX, OPEX, LCOE, CO_2 emissions, and fuel consumption. While the proposed system entails a higher net present cost of $89.7 million compared to the base system's $86.9 million, it offers potential cost savings in CAPEX and OPEX, underscoring its long-term viability and efficiency. Overall, the system simulation report serves as a valuable tool for stakeholders, providing crucial insights into design, costs, and performance, thereby facilitating informed decision-making.

Table 1: Scenario Comparison & Emission Calculation for the Electrolyser system for Hydrogen

Scenario Comparison & Emission Calculation						
Metrics	**Base System**	**Proposed System**		**Pollutant**	**Quantity**	**Unit**
Net Present Cost	$86.9M	$89.7M		**Carbon Dioxide**	9,628,107	kg/yr
CAPEX	$2.55M	$3.67M		**Carbon Monoxide**	60,690	kg/yr
OPEX	$6.53M	$6.66M		**Unburned Hydrocarbons**	2,648	kg/yr
LCOE (per kWh)	$0.77	$0.79		**Particulate Matter**	368	kg/yr
CO2 Emitted (kg/yr)	9,628,107	9,628,107		**Sulfur Dioxide**	23,577	kg/yr
Fuel Consumption (L/yr)	3,678,198	3,678,198		**Nitrogen Oxides**	57,012	kg/yr

3. RESULTS AND DISCUSSION

Based on simulations conducted using Homer Pro and Aspen Plus, an ESG metrics framework has been developed to evaluate and compare two hydrogen production systems: System A, which employs reforming in a decentralised setup, and System B, which uses electrolysis for hydrogen production and storage. System A focuses on optimizing biogas-to-hydrogen conversion, achieving a 95% conversion rate and reducing carbon emissions. System B, based on Homer Pro simulation, integrates an electrolyser with a PV system and offers potential cost savings despite a higher net present cost. The ESG heuristics encompass various aspects, including environmental considerations such as GHG emissions, energy, water, and waste management, as well as ecological impacts. Governance factors like business ethics, tax transparency, and board composition are also evaluated. Social aspects such as labour practices, employee health and safety, and human rights are included. Additionally, the framework considers business model elements like product design, cost of production, product quality, and supply chain management. The selection of the optimal system will be based on a rational decision-making process that balances economic considerations with ESG, climate, and environmental factors, aiming for the least CO_2 emissions and a sustainable supply chain. Based on the assigned numbers and weighted average theory, System A has a weighted average score of 8.72, while System B has a weighted average score of 8. Considering all factors, System A appears to have a higher score, indicating its comparative advantage in meeting ESG criteria and sustainability objectives.

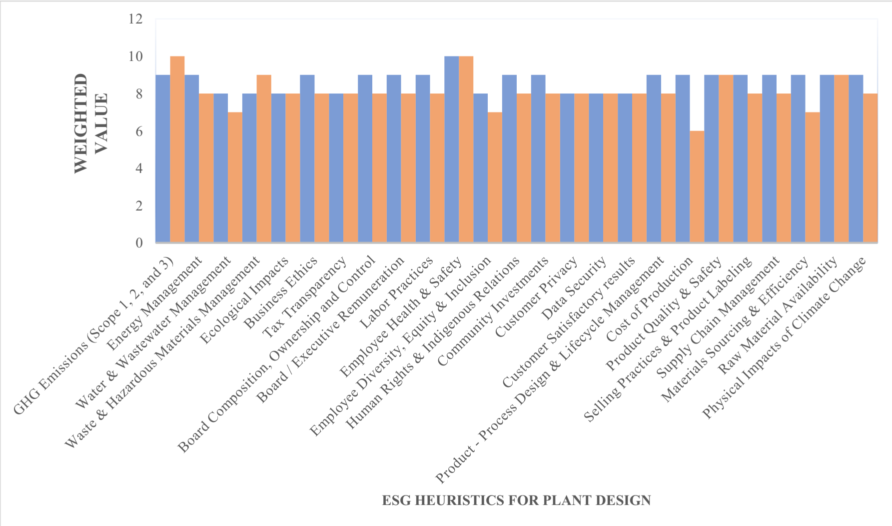

Figure 2: ESG integration into plant design for process selection and model development

4. CONCLUSION

In conclusion, this study underscores the critical importance of integrating ESG principles into decentralised process plant design to advance sustainability objectives, particularly in the transition to a net-zero future. Through the evaluation of hydrogen production technologies using reforming and electrolysis, significant improvements in efficiency and environmental impact have been identified, with tri-reforming emerging as a standout method. Leveraging ASPEN Plus® and Homer Pro software, a comprehensive ESG metrics framework has been developed to guide the selection of plant design and technology setup, with reforming of biogas identified as the optimal method. This research highlights the potential of decentralised supply chains for hydrogen production from biomass, offering a pathway toward sustainable energy solutions. Future may further explore advancements in decentralised hydrogen production technologies and their integration into broader sustainability initiatives, thereby paving the way for a greener and more sustainable future.

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6. DISCLOSURE OF INTERESTS

There is no conflict of interest between authors or any organization.

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